

# Magnetic Soliton Pair Dynamics

## Scientific Achievement

We have explored the novel physics associated with the dynamical behavior of coupled pairs of magnetic vortices trapped within small ferromagnetic ellipses. The magnetic ellipses were patterned via electron-beam lithography directly on top of a microwave guide used to detect the magnetic resonant frequencies associated with the collective motion of the spin system. While the spiral motion associated with a single magnetic vortex had been studied previously, we added a new level of the complexity to the system by introducing a second vortex into the confined structure. This enabled us to observe for the first time new excitations that arise due to the magnetostatic interactions between trapped vortices. We detected multiple resonance peaks, all in the sub-GHz frequency range. We then utilized micromagnetic simulations to identify the type of collective spin motion associated each of the observed excitations. The interpretation of the experimental data was based on non-trivial topological properties of magnetic vortices. We also introduced a new notational system to denote the relative phases of the two vortex core displacements along the major and minor axes of the ellipse, which serves as the axes of a two-dimensional coordinate system. Four different modes can be simulated that correspond to different combinations of in-phase and out-of-phase vortex core motion along these axes, three of which can be excited by the spatially uniform magnetic fields that we applied experimentally. One observed mode involves core polarizations that are parallel to each other, while the other two observable modes correspond to excitations of vortex pairs with antiparallel polarizations. The key feature we revealed is that the relative core polarizations (parallel vs. anti-parallel) determine the dynamical response. This is especially surprising since the relative core polarizations are unimportant in determining the static properties of the system, such as, the energy of the equilibrium, ground-state configuration. The vortex dynamical behavior is determined by their grovectors, which explicitly depend on the core polarizations.

## Significance

Magnetic vortices are swirling spin structures that possess two defining properties, the handedness of the swirl (clockwise or counterclockwise), and the polarity of the central core (up or down). Vortices represent collective behavior that are common in nature at all length scales, from fish swarming in the sea, and birds swarming in flight, to tornados and hurricanes in global weather systems. Magnetic vortices have cores that are nanoscale size and are often found to be the stable state (lowest-energy equilibrium configuration) in small magnetic structures. Thus, understanding their dynamics is an important research topic due to both its relevance to the fundamental advancement of the area of nanomagnetism, and its technological implications such as miniature magnetic field sensors and energy efficient magnetic random access memories.

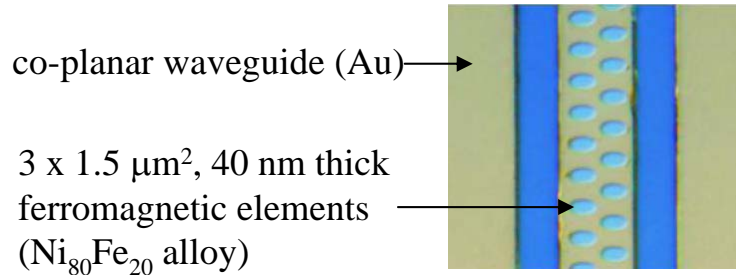
## Performers:

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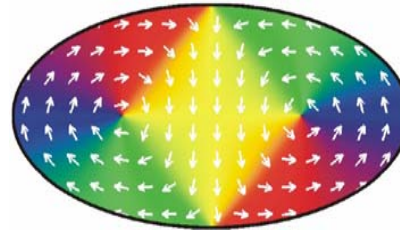
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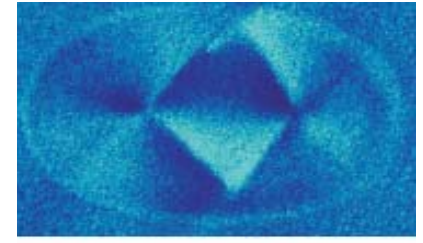
## The samples



## Magnetic vortex pair in confined geometry

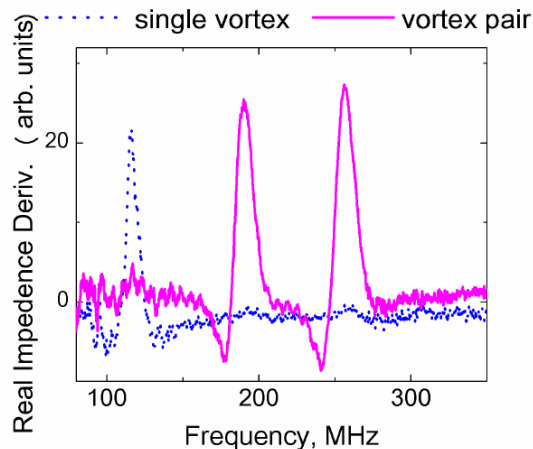


Micromagnetic model

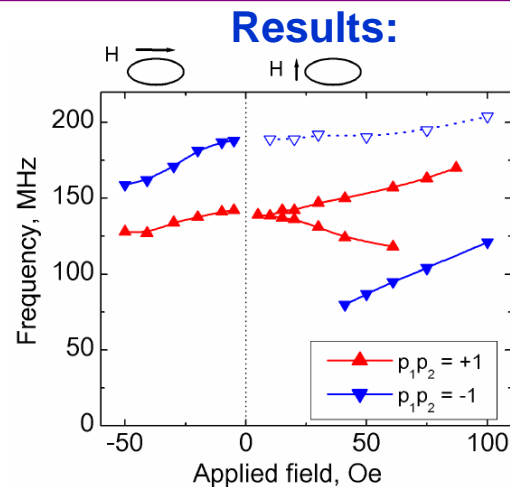


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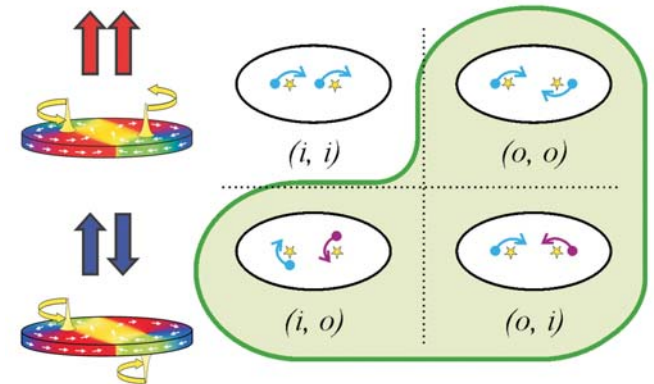
Magnetic Force Microscopy



The experimental spectra



Frequency vs. field dependence



Identified vortex pair excitation modes

**Future:** Time-resolved PEEM (ALS)

*Nature Physics* **1**, 172 (2005)

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